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Automated maintenance feasibility testing on the EU DEMO Automated Inspection and Maintenance Test Unit (AIM-TU)

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31st SOFT 2020
31ST SYMPOSIUM ON FUSION TECHNOLOGY
UK Atomic Energy Authority

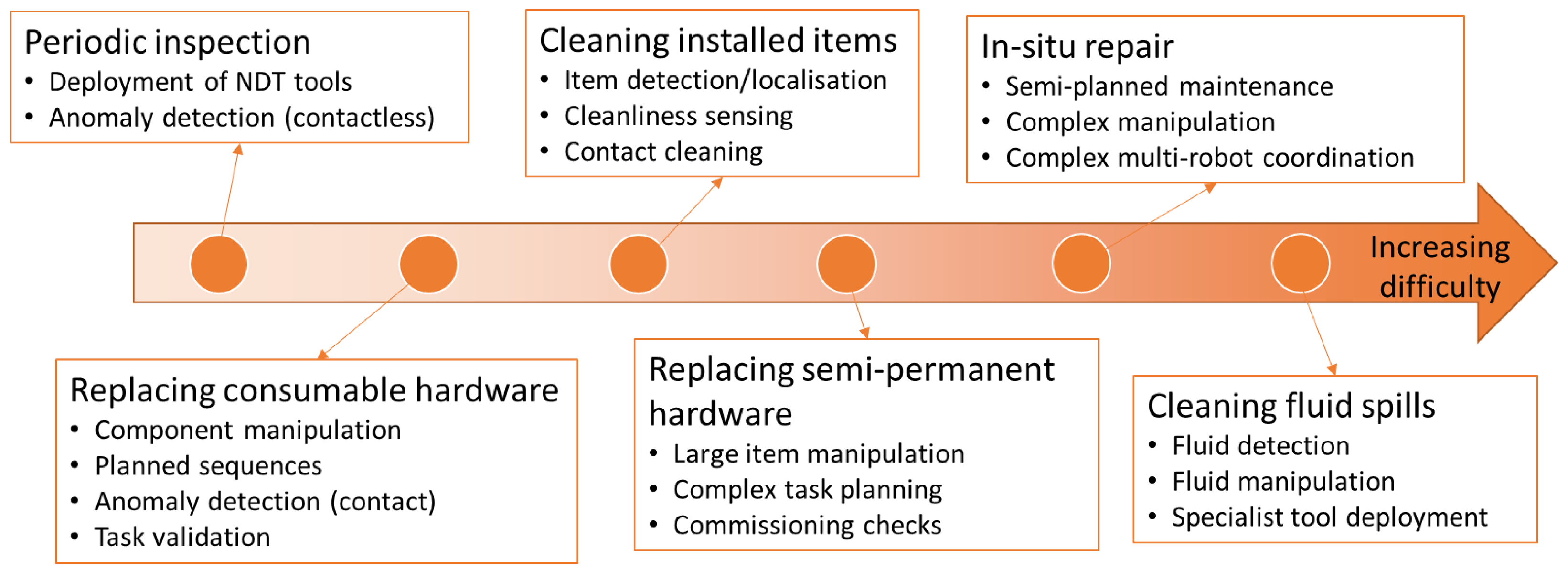
1. Background

For commercial viability fusion reactors must minimise maintenance shutdown durations. However, as reactor complexity and radiation levels increase so do the number of maintenance tasks that must be performed remotely. The remote maintenance systems of the future must therefore **perform more tasks in less time**. This requires a step change in task parallelisation and speed. Existing teleoperation approaches are inherently limited in these aspects so cannot scale to meet the challenge. Automation emerges as a potential solution, having demonstrated revolutionary productivity gains in the global manufacturing industry. The EU DEMO programme is exploring **four key research questions about Automated Maintenance:**

- Is it **feasible** in the fusion environment?
- Can it **improve** plant availability?
- Can it be **robust and safe** enough?
- How does it **change reactor designs?**

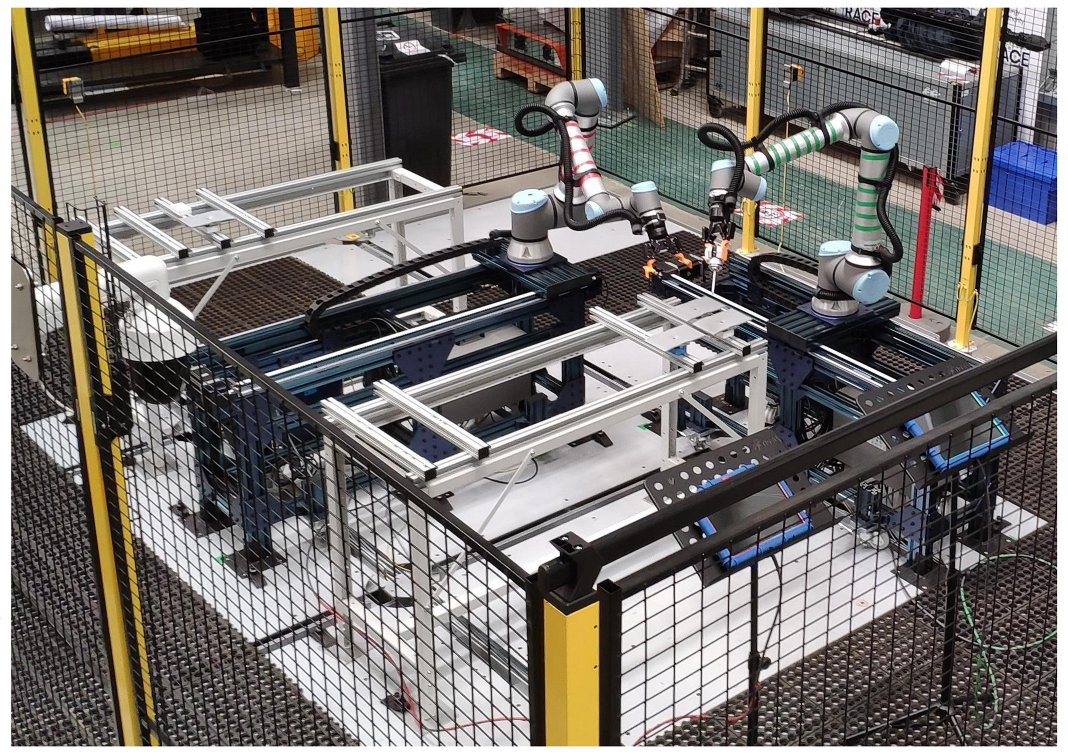
The programme will explore the feasibility of automating representative maintenance tasks under fusion conditions, excepting radiation. The proposed development roadmap shows representative maintenance tasks and the automated capabilities required.

The first two major capabilities to be studied are **anomaly detection** (both for maintenance planning and validation of task execution) and **component manipulation** (for installation and removal).

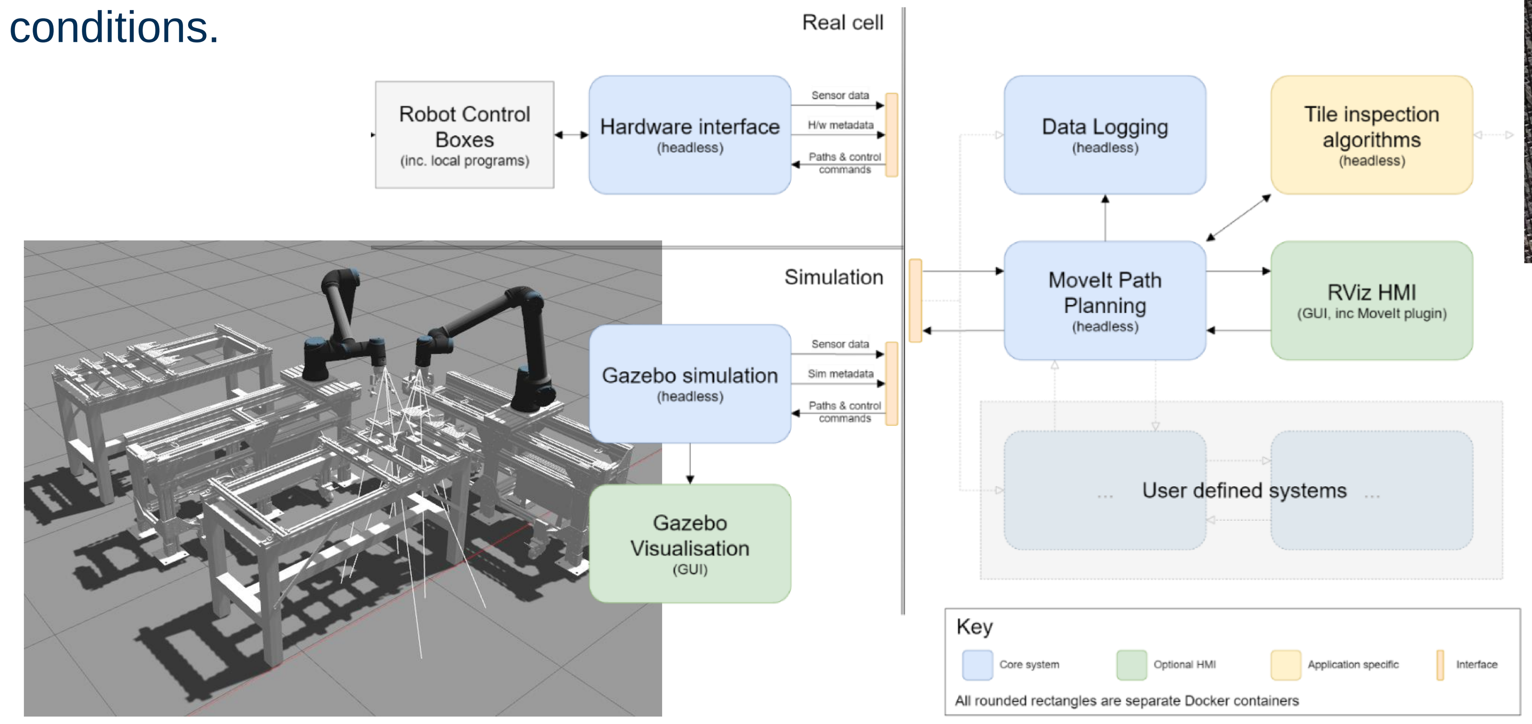


2. AIM-TU cell overview

The Automated Inspection and Maintenance Test Unit is a versatile test platform designed to support an evolving programme of Automated Maintenance research. It is a highly **modular and reconfigurable robot cell**, allowing new robot systems to be added, cell layouts to be changed, different control sources to be used, etc. The cell is equipped with two UR10e robot arms mounted on 7th axis rails, grippers compatible with JET remote maintenance tools, and a range of vision sensors (2D, RGB-D, polarisation and event cameras). An integrated safety system enables allows high-speed operation, as well as human access under reduced-speed conditions.



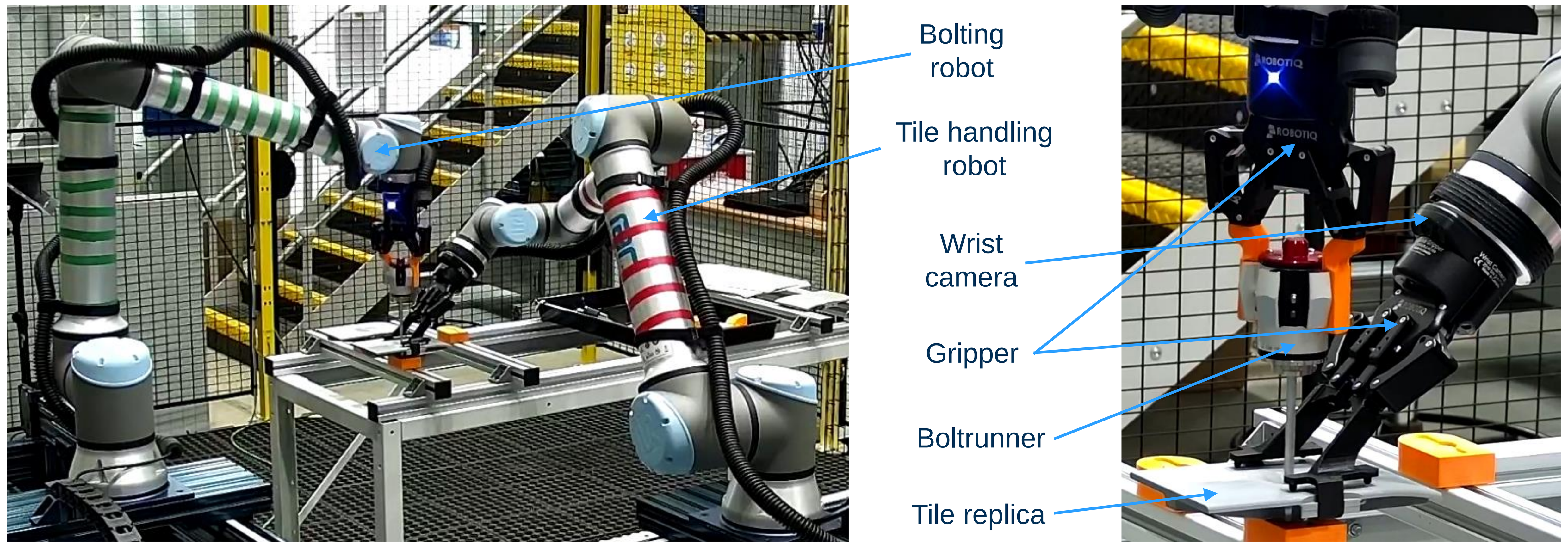
AIM-TU cell installed in the UKAEA RACE workhall



The cell is supported by a Gazebo-based simulation which enables control algorithms to be validated first in a **virtual environment**. The software architecture makes use of Docker containers to ensure maximum modularity, allowing new software tools to be added as required.

3. Automated reactor tile replacement

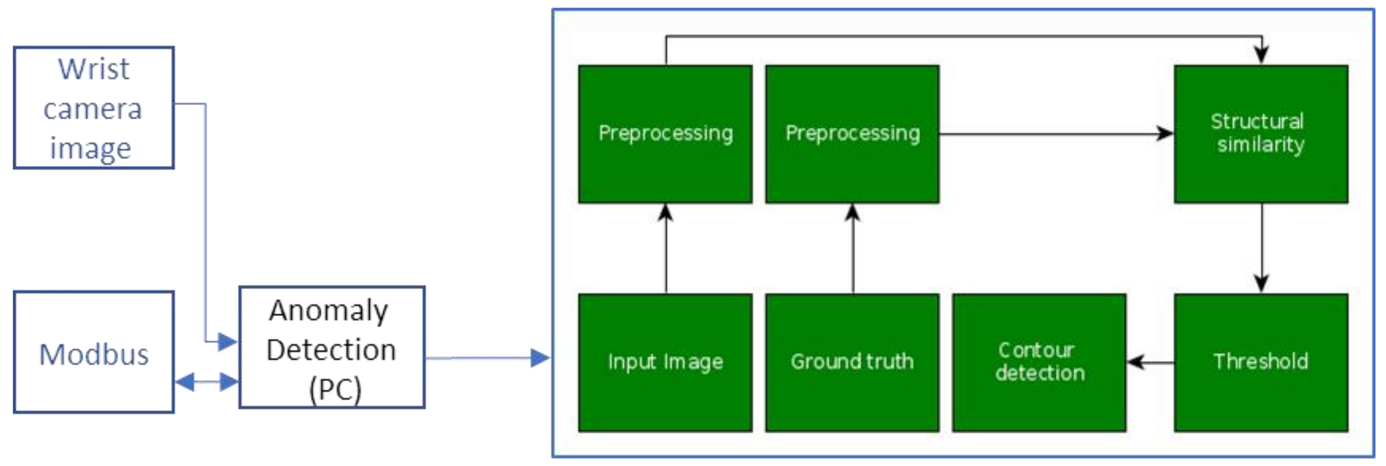
Replacement of reactor tiles is the most common maintenance task performed on JET. The task was successfully automated using two robots handling tile replicas. One robot secures the tile with its gripper while the other uses a JET boltrunner to release the tile bolt. The tile is then transferred to a storage location and exchanged for a new one, which is returned to the installation location and bolted in. The detection and location of tiles and installation/storage positions is achieved using robot's wrist cameras.

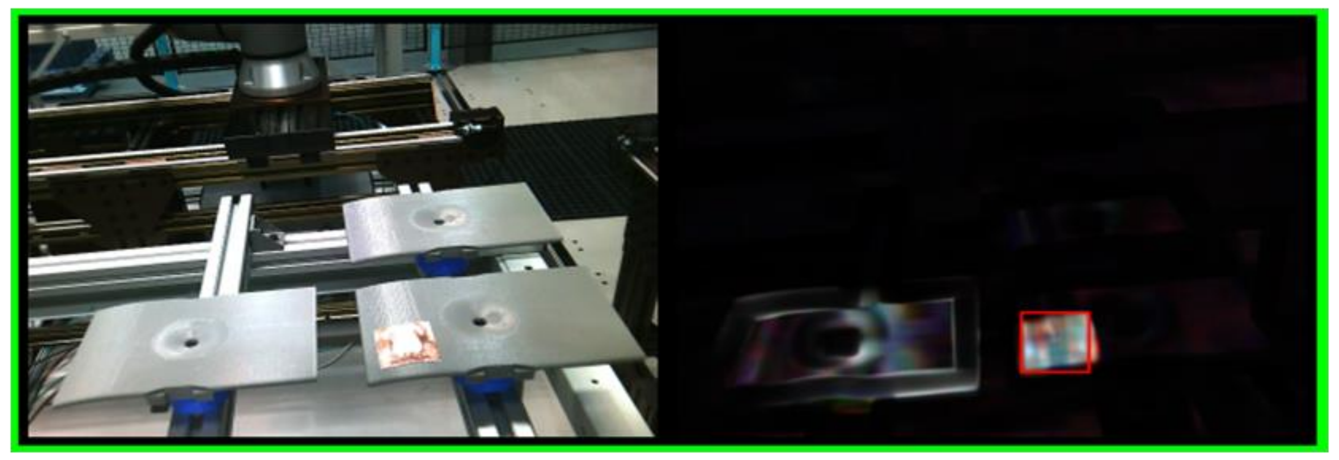


The replacement cycle was repeated 20 times. The test demonstrates the coordination of two robots to perform an automated maintenance task, the use of object detection and location technology to overcome positional uncertainty, and the use of force sensing to control the engagement between the boltrunner and the tile. Of the 40 associated tile engagements 2 failed due to the tile orientation being incorrectly determined by the camera during collection, as the tiles are rotationally quasi-symmetric. The results suggest that automated tile replacement using Commercial-Off-The-Shelf equipment is feasible, but further work is needed achieve reactor-relevant reliability. Areas of further work to improve robustness are vision-guided tile collection, sensitivity to lighting conditions, and controlled disengagement after bolting.

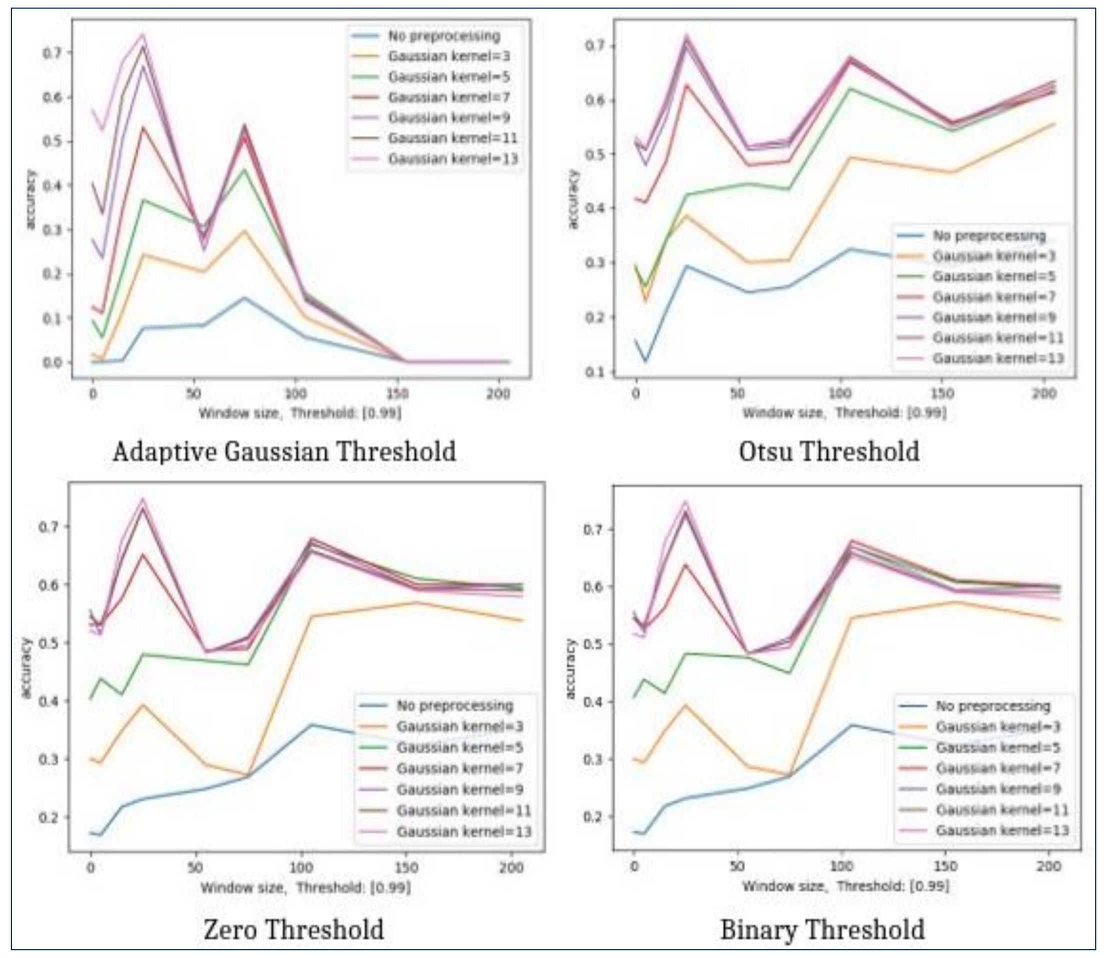
4. Contactless detection of tile anomalies

Detection of anomalies is essential for maintenance. The automation of this capability has been applied to detection of gross surface anomalies in replica JET tiles. The robot wrist cameras take images of tiles and computer vision algorithms are applied to automatically detect anomalies. The first approach trialled relies on comparing images against annotated, anomaly-free ground truth images, which does not require the large data sets necessary for machine-learning-based training.





Input image Detected anomaly



The test was carried out with multiple positions, algorithms and surface anomaly types. The criteria for successful anomaly detection was based on the intersection over union (IoU) overlap of the test image anomalies with the ground truth image. Under ideal conditions detection accuracy was highest for adaptive gaussian (100%) and Otsu thresholding algorithms (97%). However, when including disturbances (noise, image offset, discoloration), binary and zero thresholding demonstrated the best accuracy (75%). The results show that under realistic imaging conditions the approach is not sufficiently robust for a reactor setting. Hence future work will explore a combination of deep learning techniques along with structural similarity algorithms to improve accuracy and robustness to disturbances.

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